SOME ASPECTS OF THE HEAVY RAINS IN THE CHICAGO AREA, OCTOBER 9-11, 1954

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INTRODUCTION

Chicago, Ill., had its heaviest rainstorm in 69 years when 5.63 inches fell at the Weather Bureau in 24 hours between the evening of October 9, and the evening of October 10, 1954. The 6.72 inches in 48 hours, October 9–11, 1954 set a new record for that period. Reliable unofficial reports from some of Chicago's southern suburbs indicate accumulations of nearly 10 inches in 30 hours, and about 12.50 inches in 48 hours. These heavy rains resulted in what was undoubtedly Chicago's greatest flood in history. Total damage from the flood has been estimated to be approximately $10,000,000 in Chicago and $15,000,000 in suburban areas. A small tornado was reported near Homewood, Ill., on the afternoon of the 10th. Homewood is 10 miles southwest of Chicago's city limits. (c. f. Brunk [1], especially for additional information on the flooding and flood damage.)

Although the most noteworthy rains fell over northern sections of Illinois and Indiana, heavy rains also fell during the period over southern sections of Michigan and Wisconsin, northwestern Ohio, and over eastern Iowa and northeastern Missouri. Storm rainfall for the entire rain area in the United States is shown in figure 1. This is based on measurements at first-order Weather Bureau stations only. After the excessive rains in the Chicago area, a special appeal to the general public was made by the Chicago Weather Bureau Office for all available rainfall measurements. Table 1 contains the rainfall measurements received in response to this request. These measurements supplement those published in the Chicago *Local Climatological Data* and in the Illinois *Climatological Data* for October 1954. Figure 2 is an isohyetal map for October 9–11 in the Chicago area.

This heavy rain situation is of particular interest not only because of the tremendous damage which resulted but because the reasons for the occurrence of rainfall of this intensity and duration are not obvious without a careful and detailed scrutiny of weather data available before and during the storm.

Indicative of the vertical motions which must have been present is the fact that almost all of the precipitation resulted from thunderstorm activity. Most of this thunderstorm activity occurred south of a front which was in the vicinity of Chicago at the time of the initial onset of precipitation.

It is the purpose of this article to examine certain causal and influential factors, and to evaluate them, for the most part, qualitatively. In this study, we are primarily concerned with the rains in the Chicago area.

GENERAL SYNOPTIC FEATURES

On the 0030 GMT surface chart for October 8, a 1001-mb. Low appeared in the Province of Alberta. This Low

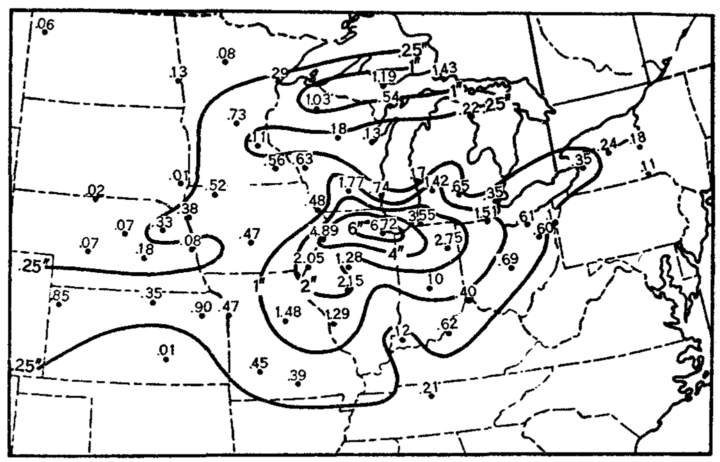

FIGURE 1.—Rainfall 0030 GMT, October 10 to 0030 GMT, October 12, 1954, for first-order Weather Bureau stations in the United States affected by the Chicago storm. Isohyets are labeled in inches.

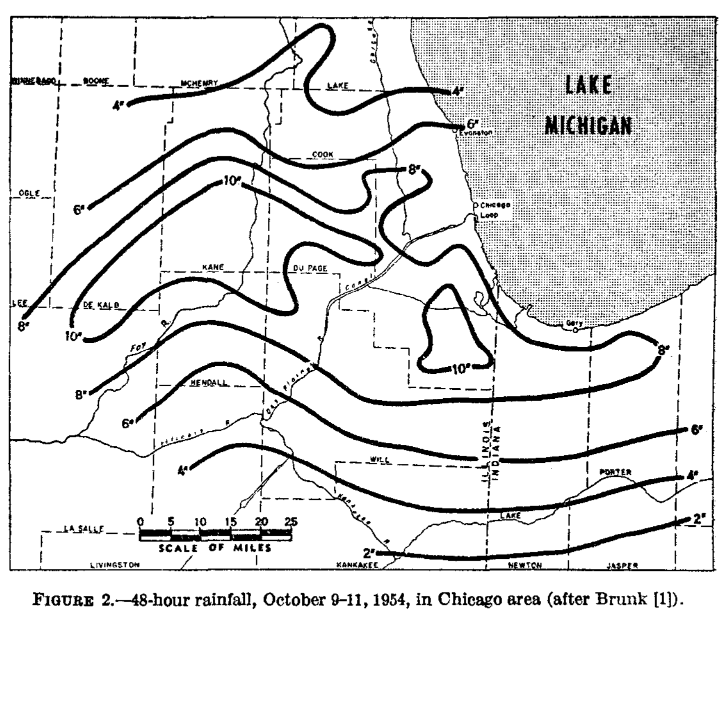

FIGURE 2.—48-hour rainfall, October 9-11, 1954, in Chicago area (after Brunk [1]).

TABLE 1.—*Special rainfall measurements in the Chicago area, Oct. 9–11, 1954*

[Amounts of rainfall are for the entire duration of the storm unless otherwise noted]

Observer	Location of gage	Amount of rainfall	Type of gage
Leonard J. Spyer	117 South Elm St., Mount Prospect, Ill	5.52	Recording rain gage.
Charles Feris, Jr	3247 Grand Blvd., Brookfield, Ill	7.04	Green type, 8-inch capacity.
Edward R. Conrad	7008 West 114th St., Worth, Ill	5.90	Pail.
Wesley E. Hackett	10445 South Prospect Ave., Chicago, Ill	8.97	Plastic, 5-inch capacity.
Charles Eggersted	3941 South Grove Ave., Stickney, Ill	7.20	6-inch capacity.
Mrs. F. van der Werff	3649 Randolph, Lansing, Ill	([1])	10-quart pail.
Mrs. W. E. Hardie	2649 Ashway Ave., Evanston, Ill	9.75	Waste basket (no dimensions).
Norman Fisher	3832 Franklin, Western Springs, Ill	7.30	Unknown.
R. C. Jenkins	6003 Woodward Ave., Downers Grove, Ill	7.02	Victor rain gage.
Judy Jay	207 North Elm, Hinsdale, Ill	11.12	School-constructed gage.
Ralph Burlingame	312 Brownell, Thornton, Ill	10.75	Cement barrel.
R. T. Fischer	Warrenville, Ill	7.00	Amateur gage.
Truex N. Upchurch	1910 Hanover Lane, Homewood, Ill	10.30	Cylindrical container.
C. W. Schelling	1 mile north of Eola, Ill	10.00	Unknown.
Mrs. John H. Beck	Warrenville, Ill	10.50	Do.
Mrs. S. K. Landak	7749 Langley Ave., Chicago, Ill	[2] 2.20	Do.
Mrs. Frances Meilleur	9646 South 55th Ave., Oak Lawn, Ill	8.80	Do.
J. M. Burgin	1½ miles east of Rd. 59, ½ mile south of Geneva Rd	5.55	Do.
Roy M. Nordine	The Morton Arboretum, Lisle, Ill	7.37	Standard Friez.
N. F. Davis	730 North Quinteur Rd., Palatine, Ill	[3] 3.70	Coffee can.
Unknown	2923 North Albany Ave., Chicago, Ill	5.20	Can.
John White	2½ miles west of Campana factory, northwest of Batavia	8.20	Unknown.
George C. Beck	3540 Gunderson Ave., Berwyn, Ill	7.98	Clint Youle.
Mrs. Charlotte Pierson	5509 North Nottingham Ave., Chicago, Ill	6.25	Round bucket.
C. Luebke	3510 West Potomac Ave., Chicago, Ill	7.50	55-gallon, open-head drum.
Mrs. R. Whitecotton	653 West Rd., Lombard, Ill	6.25	Straight-sided scrub bucket.
A. F. Ochtman	88th Ave. and 124th St., Palos Park, Ill	8.00	Unknown.
L. E. Smith	International Harvester Farm, Hinsdale, Ill. (experimental farm, 2 miles south of Hinsdale, Ill.).	6.45	Homemade Friez type.
Unknown	109th and Peoria, Chicago, Ill	[4] 7.40	Unknown.
Eugene J. Wenglowski	Near Central and Milwaukee Aves., Chicago, Ill	6.51	Do.
Charles B. Johnson	601 Hillside Ave., Elmhurst, Ill	[5] 6.25	6-inch gage.
G. W. Becker	2110 West 120th Pl., Blue Island, Ill	11.05	Small plastic.
C. L. Jones	Landon Dr., Warrenville, Ill	7.00	Unknown.
Unknown	Glen Ellyn, Ill	6.15	Do.
Mrs. F. G. Wildermuth	767 East Division St., Lombard, Ill	9.50	Bucket.
M. Matson	521 Roslyn Rd., Westmont, Ill	[6] 12.50	Tar bucket.
Ernest L. Munter	8 miles west of Medaryville and 3 miles east of Gifford, Ind	[7] 1.51	Unknown.
Lyle Olson	Leland, Ill	[8] 11.30	Homemade gage.
William W. Hograve	2 miles west of Plano and 17 miles west of Aurora, Ill	9.50	Unknown.
Fred E. H. Trowe	Chesterton, Ind	7.31	Homemade gage.
Vernell Smith	17 miles northwest of Aurora and 3½ miles south of Elburn, Ill	8.25	17½-inch metal bushel basket.
Glenn T. Koerner	Coal City, Ill	3.50	"Official" gage.
Mrs. Bernice Wellman	Wauconda, Ill	[9] 5.50	Boat.
David C. Johnston	Alfred St., Porter, Ind	8.80	Unknown.
Mrs. Lewis Nichols	230 Wells St., Crown Point, Ind	7.80	Standard type.
Mrs. Russell J. Carson	5 miles north of Wanatah, Ind	7.25	Unknown.
Mrs. Melvin Most	Crete, Ill	8.75	12-inch pail.
Mrs. Anton J. Senty	954 Sylvan Circle, Naperville, Ill	9.00	Unknown.
Thomas B. Casey	Location: Latitude 41°37′33″, longitude 87°57′03″	9.45	Recording rain gage of Illinois Division of Waterways.
Radio Station WTAQ	South of La Grange, Ill	5.00	Unknown.
C. B. Jewell	Manteno, Ill	5.40	Do.
Mr. and Mrs. Thos. Williams	Center Rd., Route 1, Frankfort, Ill	9.25	Do.
William Hubbe	Huntley, Ill	3.20	Graduated glass tube.
L. D. Williams	Armour Research Foundation of Illinois Institute of Technology, Lafox, Ill	11.20	Rain and snow gage purchased from Standard Science Supply Co.
Nelavu Reed	208 East 5th St., Lockport, Ill	8.50	Unknown.
John Loughridge	Junction Routes 59 and 20, east of Elgin, Ill	4.65	Graduated glass tube.
Robert Ward	Duneland Observatory, Ogden Dunes, Ind	7.10	Unknown.
Leonard Makila	Addison, Ill	5.33	Do.
Mr. Goodwin	About 219th on Maple Ave., west of Park Forest, Ill	8.50	5-gallon pail with straight sides.
Unknown	Tinley Park, Ill., northeast section near 167th St	8.40	Unknown.
W. R. Petersen	5344 Conrad, Skokie, Ill	8.36	Victor rain gage.
Bob Smith	723 South Blvd., Evanston, Ill	7.20	Large container.
Frank Wachowski	2138 West 19th St., Chicago, Ill	8.34	Unknown.
McDonald	8100 South Keating Ave., Chicago, Ill	5.75	12-inch bucket.
Electromotive Division, General Motors	La Grange, Ill	6.62	Unknown.
Unknown	Near 109th and Peoria, Chicago, Ill	7.40	Do.
Argonne National Laboratory	Lamont, Ill	8.64	Do.
Unknown	1707 South Jefferson St., Chicago, Ill	6.50	12-inch bucket.
Do	Bensenville, Ill	8.00	10-gallon bucket.
Do	3704 West 81st St., Chicago, Ill	7.50	Ice bucket.
Do	10736 South McVickers, Chicago Ridge, Ill	7.25	Tapered garden cart.
W. B. Bailes	117 West North St., Hinsdale, Ill	5.25	Unknown.
Unknown	3 Luthin Rd., Hinsdale, Ill	7.10	Standard plastic gage.
Do	806 Dempster, Evanston, Ill	6.50	Gallon bucket.
Do	5218 North Oak Park Ave., Chicago, Ill	7+	Scrub bucket.
Do	140th and Central, Midlothian, Ill	10.50	Pail.
Do	Near Montrose and Central Aves., Chicago, Ill	8.75	30-inch washtub.
Mr. Foote	Dolton, Ill	10.00	18-inch pail with sloping sides.
Mr. Aherns	844 South Garfield Blvd., Chicago, Ill	[10] 5.34	Unknown.
Unknown	77th and South Langley, Chicago, Ill	[11] 2.00	Clint Youle.

[1] 1 inch from top of pail.
[2] 2 p. m. Oct. 11–8 a. m. Oct. 12.
[3] Up to 8 a. m. Oct. 11.
[4] Up to about 6 p. m. Oct. 10.
[5] Estimated, 6-inch gage overflowed.
[6] 12½-inch deep tar buckets overflowed.
[7] Oct. 11 and 12.
[8] Estimated.
[9] 24-hour period after beginning of rain.
[10] 9:18 a. m. Oct. 10–7: 10 p. m. Oct. 11.
[11] 2 to 3:20 p. m. Oct. 11.

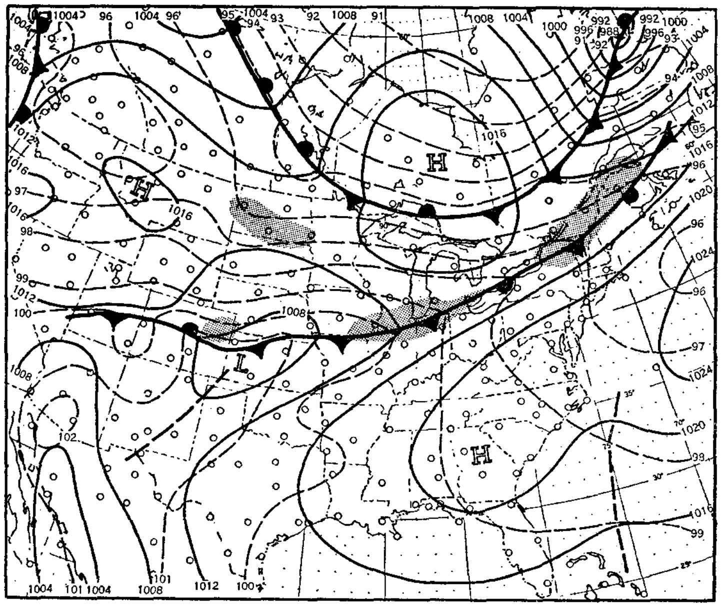

FIGURE 3.—Surface chart at 0330 GMT on October 10, 1954 and 1000 mb. to 700 mb. thickness contours in hundreds of feet (dashed) at 0300 GMT on October 10, 1954. Shading shows areas of active precipitation.

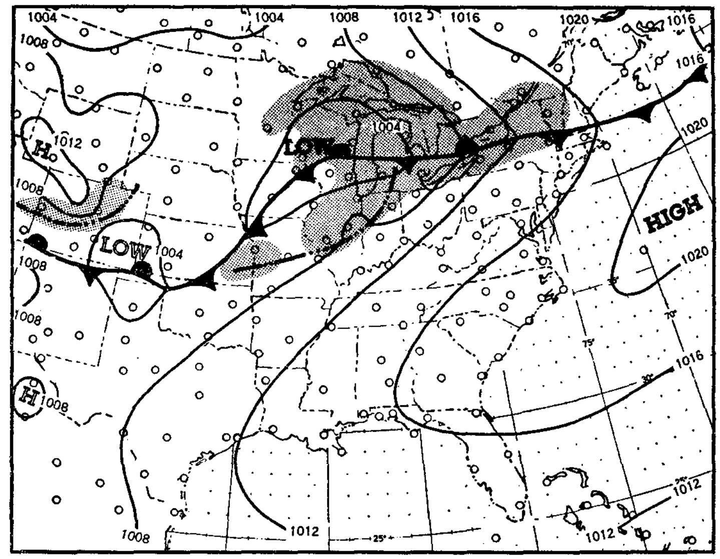

FIGURE 5.—Surface chart at 0330 GMT on October 11, 1954. Note the squall line extending from Michigan through southern Illinois to eastern Kansas.

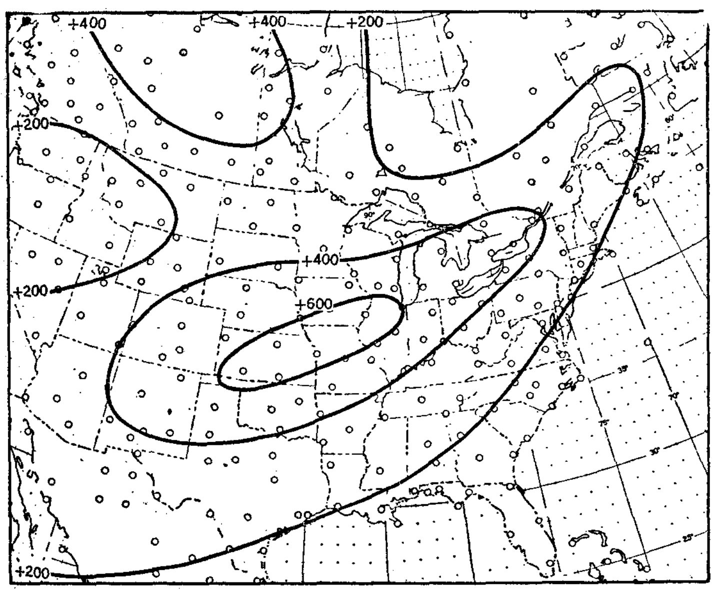

FIGURE 4.—Departure from normal 1000 mb. to 500 mb. thickness at 0300 GMT October 10, 1954, labeled in hundreds of feet. Note that in the area from Chicago southwestward thickness of this layer is 600 ft. or more above normal for October.

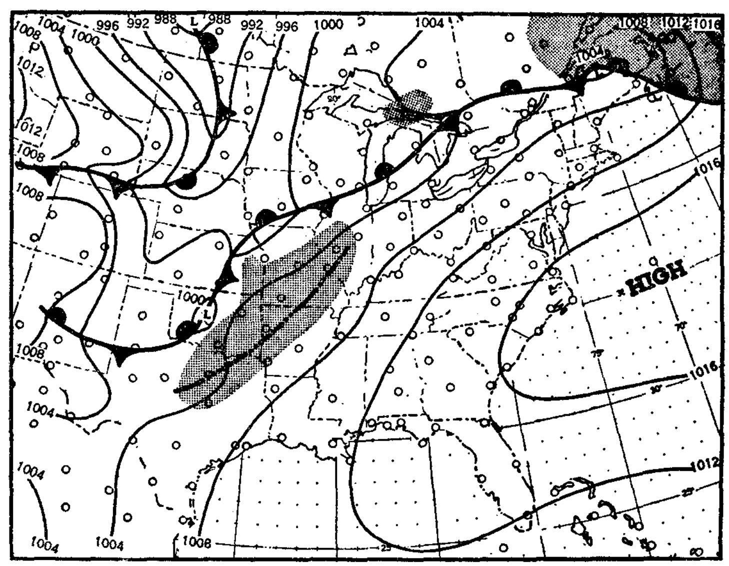

FIGURE 6.—Surface chart at 0330 GMT on October 12, 1954. Chicago is no longer in the precipitation area. The front over the Dakotas passed Chicago by 1230 GMT on October 13, 1954.

moved eastward with a speed of 30 knots. At 0330 GMT, October 10 (fig. 3), it was centered over northern Labrador and had deepened to 987 mb. From this cyclonic circulation, a front extended southwestward to just south of Chicago,[1] then westward to southern Nevada. This map time was about 4½ hours after the Chicago Weather Bureau Office's first report of heavy showers. The dashed lines in figure 3 are thickness lines between 1000 and 700 mb. Since thickness lines are isotherms of mean virtual temperature, the thermal intensity of the front is clearly shown. Three hours later, the front had moved north of Chicago as a warm front, and throughout the remainder of the precipitation period in the Chicago area, the charts show Chicago in the warm air.

From the same cyclonic circulation in Labrador, a cold front extended through southern Canada, about 200 miles north of the front through the United States, to Fort Smith, District of MacKenzie. By 1530 GMT on the 10th, the eastern portion of this front had replaced the front over the United States, and the western portion had frontolized.

A weak low circulation which first appeared over central South Dakota late on October 8 drifted slowly southward,

[1] Due to the influence of precipitation and thunderstorms on the parameters used to locate fronts, the exact position of that segment of the front through northern Illinois at this time is difficult to determine.

and at 0330 GMT on the 10th, it was analyzed as a 1005-mb. center over western Kansas.

South of the front, the western nose of the Atlantic high cell dominated the circulation over the Eastern States. The High, centered near ship Delta (44° N, 41° W), had been a principal feature of the weather charts for the preceding ten days as it migrated southward from north of the Arctic Circle. At one time, its circulation covered all of the United States east of the Continental Divide and eastern Canada south of the 55th parallel. Indicative of the warm air being brought northward by the southerly flow on the western periphery of the High for 36 hours prior to the Chicago rains was the 1000 to 500-mb. thickness departure from normal chart for 0300 GMT on the 10th (fig. 4). This shows that the thickness of this layer over Chicago and a 200-mile wide area southwestward to northwestern Oklahoma was over 600 ft. above normal for October. This corresponds to temperatures over 9° C. above normal.

The weak Low in Kansas on October 10 moved northeastward and at 0330 GMT, October 11 (fig. 5) was centered about 170 miles northwest of Chicago and had deepened to 1001 mb. At this time, the surface chart showed a well defined squall line from Gladwin, Mich., to Chanute, Kans. Other squall lines developed in the warm air during the period of the Chicago rains, but none of these apparently extended northward to Chicago. The Low northwest of Chicago proceeded rapidly east-northeastward along the front and was centered near Caribou, Maine at 0330 GMT on the 12th (fig. 6).

Through the United States, the quasi-stationary front (fig. 6) was essentially dry. On this chart most of the precipitation was associated with the squall line in the warm air. The dry quasi-stationary front remained west of Chicago until the cold front from the northwest had reinforced it by 1230 GMT on the 13th.

The 500-mb. flow over North America during the period of heavy rains at Chicago was predominantly zonal. The strong westerlies were responsible for the rapid movement of the surface Low which originated over Alberta on October 8. At 0300 GMT, October 10, a 500-mb. High was centered over Alabama with a weak ridge extending north-northwestward to just east of International Falls, Minn. (fig. 7). Farther west, this chart showed an area of weak cold advection eastward from a north-south trough extending from western Montana to southwestern Utah. This advection resulted in 300 to 500 ft. of

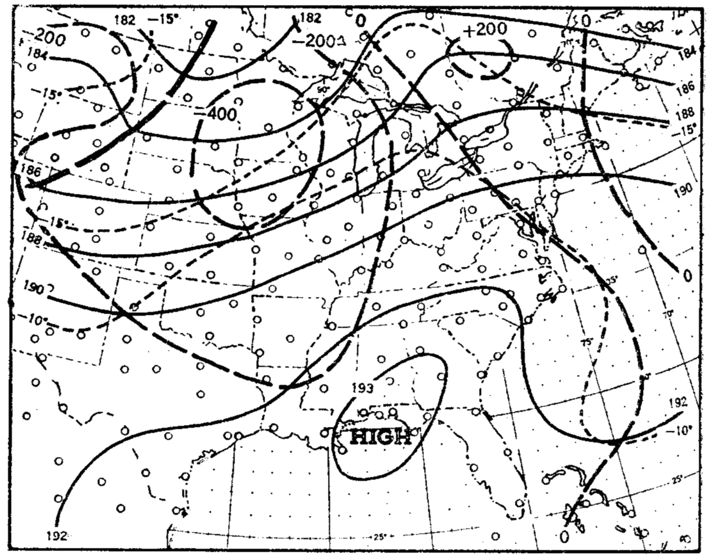

FIGURE 8.—500-mb. chart at 0300 GMT on October 11, 1954. Note the height falls west of Chicago.

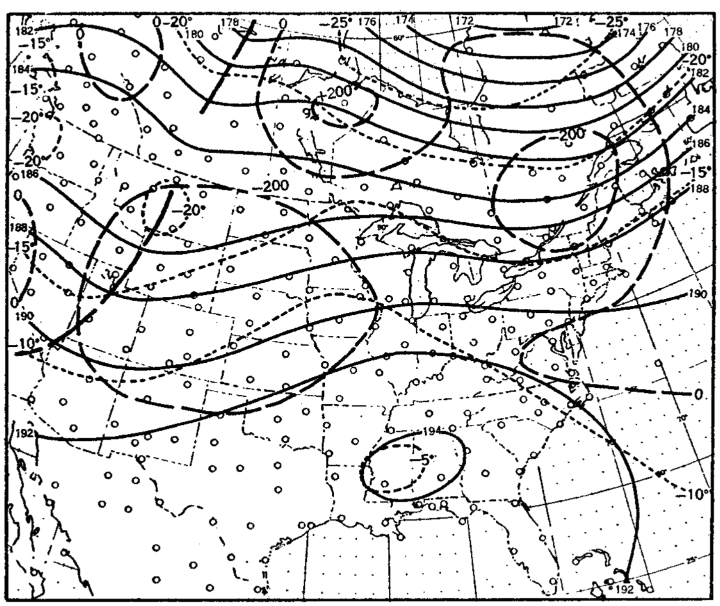

FIGURE 7.—500-mb. chart at 0300 GMT on October 10, 1954. Solid lines are contours in hundreds of geopotential feet. Short dashed lines are isotherms labeled in degrees Celsius. Longer dashed lines denote height changes in feet during the preceding 24 hours. The trough is indicated by a broad dashed line.

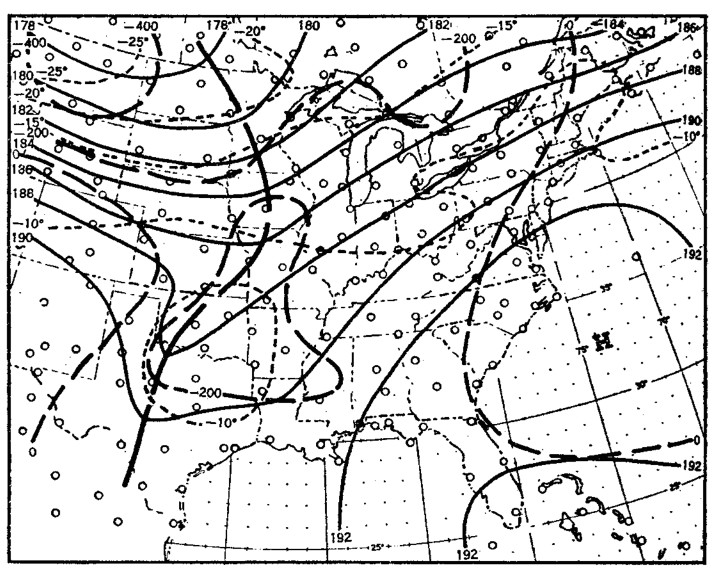

FIGURE 9.—500-mb. chart at 0300 GMT on October 12, 1954.

deepening in the next 24 hours as the ridge migrated eastward. At this time (fig. 8), the trough was well defined from east of Le Pas, Manitoba to southeastern Utah. Twenty-four hours later, this trough had moved eastward to the position shown in figure 9, causing a slight backing of winds to its east.

INFLOW OF MOIST AIR

The inflow of moist air into the storm area was studied with the aid of precipitable water computations. Solot [2], in 1939, presented a tabular method of computing the value of precipitable water in a column of air from aerological soundings. Although his method was much simpler than previous methods of computing this very significant meteorological parameter, precipitable water was still too inconvenient to compute to have wide use in routine rainfall forecasting. Showalter [3] has recently devised a template with which the precipitable water can be readily obtained from the dewpoint curve on pseudo-adiabatic diagrams. Precipitable water in inches is computed in increments from the surface to 400 mb.

Using Showalter's template, computations of precipitable water were made from soundings taken at 0300 GMT for the period October 8–11, and for 1500 GMT, October 12. Data for 1500 GMT instead of 0300 GMT were used for the 12th because much of the 0300 GMT data desired for other computations were missing. Values of precipitable water were plotted on charts and isolines at 0.50-inch intervals were constructed (figs. 10–14).

Note the high precipitable water values in the vicinity of Topeka, Kans. at 0300 GMT on the 8th (fig. 10), almost two days before the heavy rains began at Chicago. The fact that very moist air moved into the Chicago region is clearly shown by the successive charts. Figure 11 shows that by 0300 GMT on the 9th, the area of precipitable water content of 1.25 inches and above had expanded into southern Iowa, southeastern Nebraska, northern Missouri, and west-central Illinois. By the 10th at 0300 GMT (fig. 12) further expansion of the area had taken place extending it through Indiana, Ohio, and southern Wisconsin, and there were several computations of precipitable water in excess of 1.50 inches. Figures 13 and 14 show the progression of the area of high precipitable water values through Michigan and New York on into the New England States.

In an effort to determine how values of precipitable water in this storm compared with those in other rain-

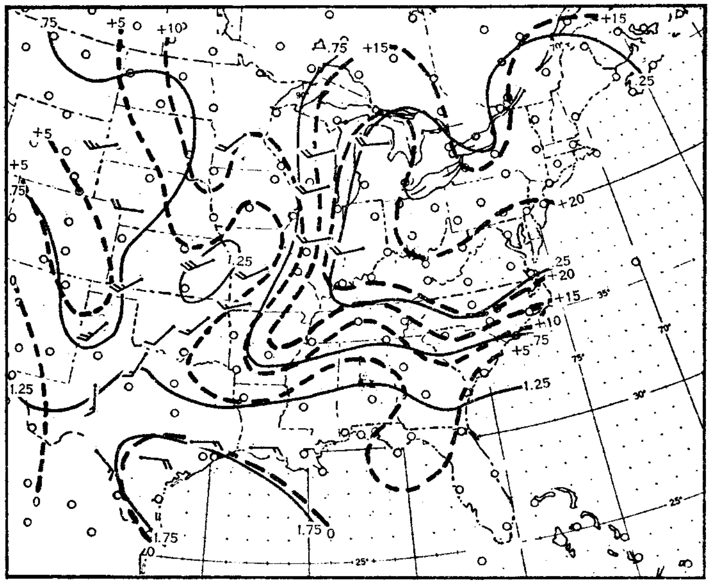

FIGURE 10.—Precipitable water in inches (solid lines), Showalter stability indices in degrees Celsius (dashed lines), and average winds between gradient level and 20,000 ft. at 0300 GMT, October 8, 1954. Henceforth this type chart will be referred to as the precipitable water chart.

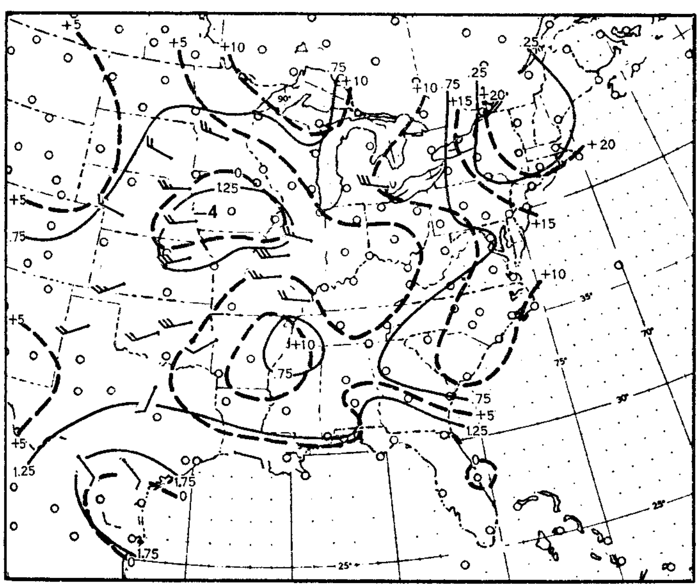

FIGURE 11.—Precipitable water chart at 0300 GMT on October 9, 1954. Note the −4° C. Showalter stability index at Omaha.

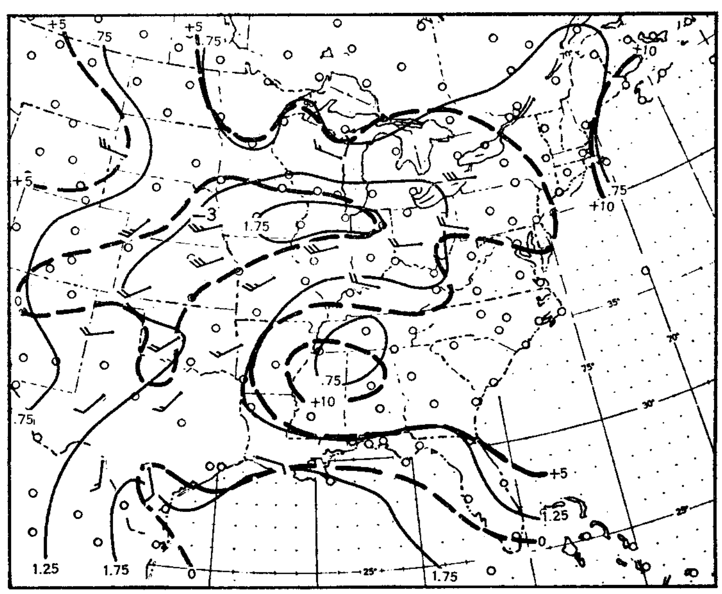

FIGURE 12.—Precipitable water chart at 0300 GMT on October 10, 1954. Precipitable water in the Chicago area has increased markedly and Showalter stability indices are low. Omaha has an index of −3° C.

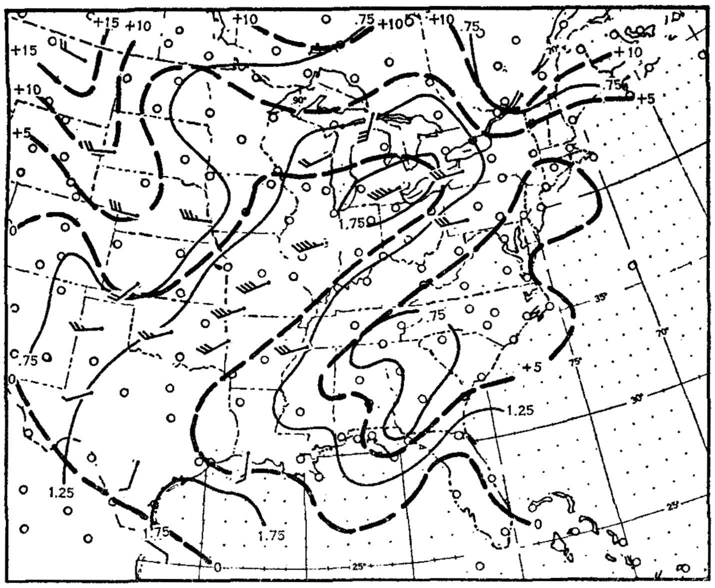

FIGURE 13.—Precipitable water chart at 0300 GMT on October 11, 1954.

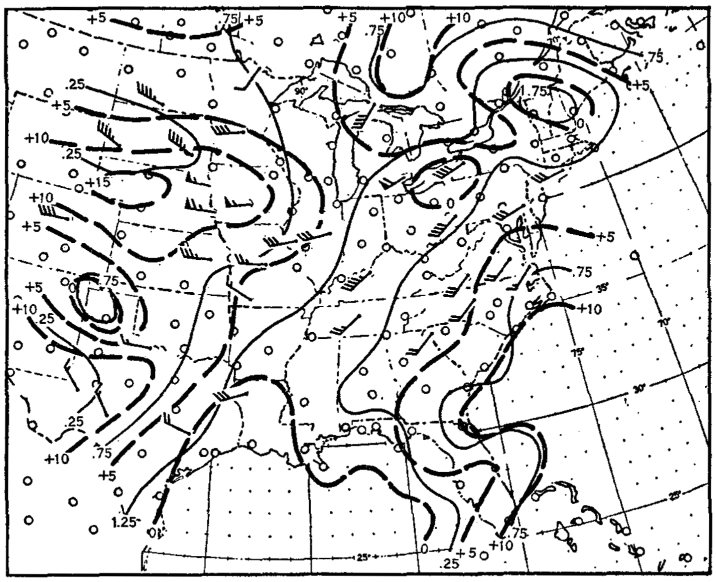

FIGURE 14.—Precipitable water chart at 1500 GMT on October 12, 1954. Drier, more stable air is invading the Chicago area from the Northern Great Plains.

storms, *Hydrometeorological Report* No. 25A [4] was consulted. This report gives the representative dewpoint of each major storm east of the Continental Divide for which dewpoint data had been processed as of June 1949. Included are storms since 1867. From this list, dewpoints of all storms occurring in October north of 35° latitude were tabulated. Sixteen storms fell into this category. Dewpoint values ranged from a low of 60° to a high of 74° F. The average was found to be 66°. It is worthy of mention that none of these October storms occurred west of the Great Plains.

The average dewpoint found in past October storms compares favorably with observed values in the Chicago rainstorm. During their initial thundershower period the Chicago Weather Bureau Office reported dewpoints. of 66°. Assuming a pseudo-adiabatic lapse rate, this corresponds to precipitable water content up to 400 mb. of 1.83 inches. Radar reports had indicated cloud tops to 40,000 ft. Therefore, with heavy rain falling, assumption of a pseudo-adiabatic lapse rate seems reasonable. This is justification for the 1.75 isoline on the precipitable water chart for 0300 GMT on the 10th (fig. 12) although there were no values of this magnitude computed from aerological soundings. It is unfortunate that no soundings are made at Chicago. The closest aerological soundings to Chicago are in the fringe area of the heavy rains which developed. Dewpoints observed at Chicago in this storm equalled those in three, and exceeded those in six, previous major October storms over and east of the Great Plains.

Computations of precipitable water showed generally high moisture content of the atmosphere to the southwest of Chicago up to the 500-mb. level. The amounts of precipitable water between 500 and 400 mb. were very small, ranging from none to a maximum of 0.09 inch. Since this quantity is only a small percentage of the total precipitable water, it may be neglected.

Sizable quantities of precipitable water up to 500 mb. necessitated a consideration of the wind circulation from gradient level to the 500-mb. level in order properly to explain the movement of the moisture in the Chicago area. To approximate the mean wind flow in this stratum, an average wind from gradient level to 20,000 ft. was computed using data from each 2,000-ft. reporting level on the pibals. These winds were plotted on the precipitable water charts both to show the trajectory of the moisture and to give an indication of the rate of inflow of this moist air into the Chicago area. Unfortunately, many of the wind observations ended below 20,000 ft. and the number of average winds for the stratum from gradient level to 20,000 ft. was too limited to pinpoint an axis of strongest average wind. However, enough data were obtained to clearly indicate the general wind flow from the Gulf of Mexico into the Chicago area. Movement of areas of high precipitable water can also be justified from these average winds. Figure 10 shows easterly winds of 15 to 20 knots on the Texas and Louisiana Gulf Coast initially bringing in the moisture. The charts at subsequent 24-hour intervals show veering of these winds and increasing southwesterly winds from north Texas through the Chicago area. The much drier air over the Northern Great Plains moved eastward with the westerly average winds which gradually strengthened. As shown on the charts, there was a marked decrease of precipitable water over northern Illinois between 0300 GMT on the 11th and 1500 GMT on the 12th.

STABILITY INDICES

To evaluate the degree of stability of the warm moist air, Showalter stability indices [5] were computed for each of the soundings used in obtaining precipitable water. Isolines of these values are the dashed lines in figures 10 through 14. Negative values indicate instability and posi-

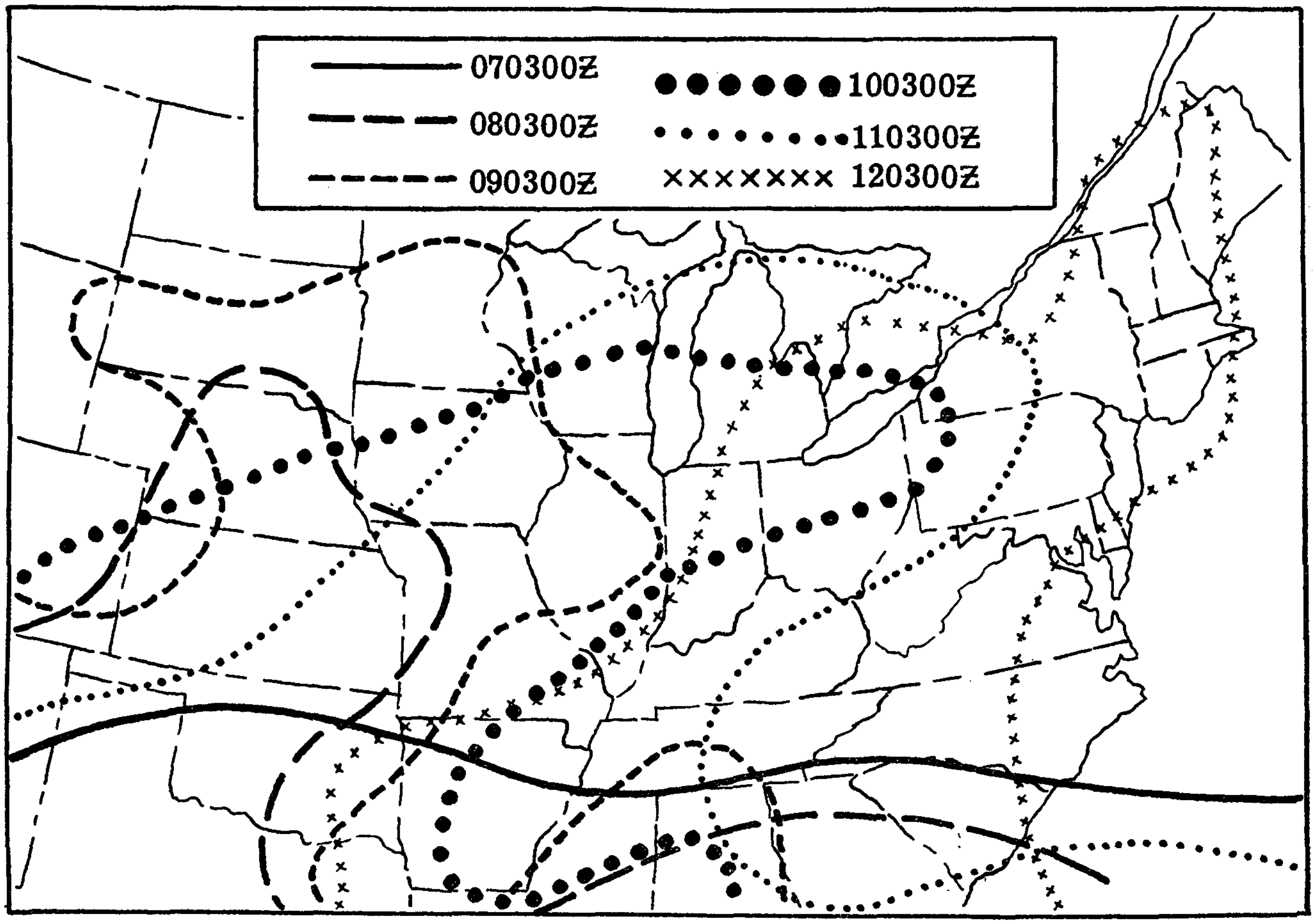

FIGURE 15.—Progression of the 10° C. isodrosotherm at the 850-mb. level from 0300 GMT on October 7 to 0300 GMT on October 12, 1954.

tive values, stability. As mentioned by Showalter [5], experience has shown that any positive value of +3° or less is very likely to be associated with showers and quite likely to produce thunderstorms. Thunderstorms have increasing probability as the index falls from +1° to −2°. Values of −3° or lower may be indicative of severe thunderstorms.

The patterns of stability indices show that the warm moist air coming up from the Gulf of Mexico and flowing into the Chicago area had sufficient instability according to the above criteria to produce thunderstorms. Note how well the patterns of precipitable water correspond to the patterns of stability with high stability in areas of low precipitable water and low stability in areas of high precipitable water. Since the stability index is based upon moisture at the 850-mb. level only, this points out the well known fact that the largest quantity of precipitable water in a column of air is in the low levels. It also indicates that the stability index is significant in determining available moisture as well as degree of stability.

The progression of the zero isoline of stability indices shows the increasing probability of thunderstorms in the Chicago area. Even the possibility of severe thunderstorms was indicated by the −4° stability index at Omaha on the 9th at 0300 GMT. Omaha was directly upstream from Chicago. On the 10th at 0300 GMT Omaha had an index of −3° and the unstable air was again pouring directly into the Chicago area as shown by the average winds.

Figure 15 shows the progression of the 10° C. isodrosotherm at 850 mb. before and during the storm. This pattern of progression is also similar to that of the areas of high precipitable water content and indicates that low level warming is the primary cause of the increasing instability downstream. Further evidence of this is the 12° C. increase in surface temperature at Omaha between 0300 GMT on the 8th and 0300 GMT on the 9th. During this period, the temperature at 850 mb. and 700 mb. increased 11° and 4° C., respectively, and the 500-mb. temperature decreased 2° C.

OTHER LOW-LEVEL FEATURES

The similarity of patterns of the three parameters, viz, precipitable water, stability index, and 10° C. isodrosotherm at 850 mb. directed our attention to the lower levels of the atmosphere for other possible features of significance.

Means [6], in a comprehensive study of the occurrence and forecasting of thunderstorms in the central United

States, has associated thunderstorms with low-level warm geostrophic advection as defined by cross patterns of isotherms and contours. "These cross patterns are associated not only with up-slope convergence and differential advection but also with strong vertical wind shears." Means also pointed out that narrow air streams or jets of supergeostrophic winds are frequently found at lower levels in advance of pressure troughs. These jets cause strong localized warm advection and their horizontal shear patterns play an important role in creating areas of convergence and divergence in the lower levels. Little can be added to Means discussion [6], and our main purpose here is to show that many of the features covered in his article were present in connection with the Chicago rains.

Isotachs were drawn from 12-hourly 850-mb. rawinsonde data for the period beginning approximately 20 hours before the Chicago Weather Bureau Office first reported heavy rains and ending about 8 hours after the rain period. The 5,000-ft. winds from all available pibals were used to assist in the analyses. There was at least one well defined narrow air stream or jet in the warm air on each of these charts. Figure 16 is a vertical cross section of wind speeds across the jet at 0300 GMT on October 11.

The core of the low-level jet is not necessarily at the 850-mb. level. To ascertain the level or levels of the core of the jet, the strongest reported wind between gradient level and 8,000 ft. for each station was plotted on a separate chart. This was done at 12-hourly intervals for the times corresponding to the 850-mb. charts. Analyses of these data showed that for the most part the strongest wind was at the 5,000-ft. level (approximately 850-mb. level). In cases where the strongest wind was at another level, it usually was not much stronger than the wind at 5,000 ft. The axes of strongest winds on the two charts for a given time did not differ significantly.

Because the 850-mb. charts were found to be satisfactory to demonstrate the low-level jet and because temperature patterns could readily be obtained from these charts, use of this level was made in this phase of our study.

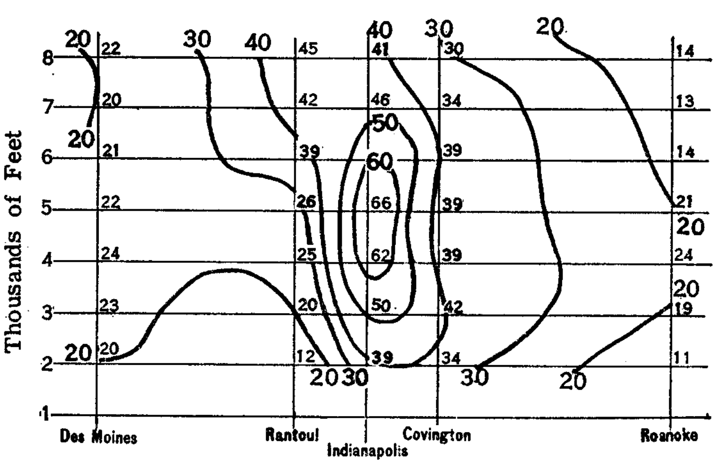

Figure 16.—Vertical cross section of wind speeds between Des Moines, Iowa and Roanoke, Va. at 0300 GMT on October 11, 1954. Speeds are in knots.

Having already determined the existence of a low-level jet, the next step was to interrelate, if possible, the jet with the thermal field to locate areas of strong warm advection. In addition, isotach patterns were examined to determine areas of strong cyclonic shear. At 0300 GMT and 1500 GMT, October 9, there was an 850-mb. jet extending from the eastern edge of the Texas Panhandle through northern Illinois with the jet maximum over southeastern Kansas and northern Oklahoma. A warm tongue extended east-northeastward from western Kansas through northern Illinois. At 0300 GMT on the 10th (fig. 17), the axes of the warm tongue and jet lay in approximately the same positions held on the 9th. However, the temperature gradient in northern Illinois and northern Indiana had increased considerably, the jet had intensified and winds over northern Illinois and northern Indiana were about 30 percent stronger, and there was an increased amount of moisture and instability available.

Advection rates were computed and found to be about 2° C. per 3 hours at Chicago and about 1½° C. per 3 hours in southeastern Iowa, northern Indiana, and the remainder of northern Illinois. Advection elsewhere in the area bounded by figure 17 was 1° C. or less per 3 hours. Although the winds were stronger from the Texas Panhandle to northeastern Missouri, the streamlines (not indicated in fig. 17) were almost parallel to the isotherms. At 1500 GMT, October 10 (fig. 18), the area of strongest warm advection is seen by inspection to have been in northwestern Illinois. The temperature gradient there had increased due both to warming from the southwest and to precipitational cooling over north-central Illinois and northern Indiana. At 850 mb., Rantoul, Ill., had cooled 3° C. while Columbia, Mo. had warmed 2° C. Moline, Ill., accumulated twice as much rain (3.65 inches) in the 12 hours between 0630 and 1830 GMT as Chicago (1.83

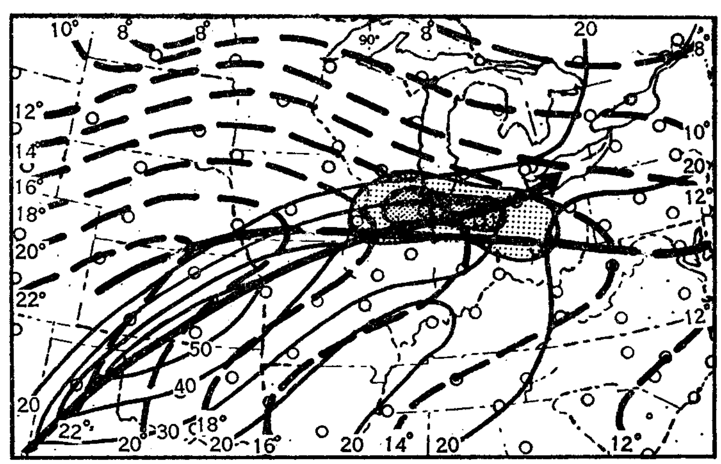

Figure 17.—850-mb. chart at 0300 GMT on October 10, 1954. Heavy solid line is axis of jet. Heavy dashed line is axis of warm tongue. Light solid lines are isotachs labeled in knots. Light dashed lines are isotherms labeled in degrees Celsius. Light shading denotes rainfall of over 0.25 inches in period beginning 8½ hours before and ending 3½ hours after chart time for first-order stations in United States. Heavy shading indicates rainfall of over an inch in the same period. Note that the axis of the jet and the axis of the warm tongue cross in northern Illinois.

inches). During the preceding 12 hours, Chicago had accumulated nine times as much (2.33 inches) as Moline (0.26 inch). The jet maximum which was still located in southeastern Kansas and northern Oklahoma had intensified to about 70 knots.

During the next 12 hours, the jet maximum decreased slightly in intensity and moved into the Indiana and western Ohio area as the jet axis migrated southeastward. At this time (fig. 19) warm advection over the Chicago area was weak. However, northern Illinois and northern Indiana lay in a zone of strong horizontal convergence. Both increasing cyclonic shear downstream and northward displacement of air were contributing to an increase in absolute vorticity. It will be shown later that there was concurrent strong divergence in the high troposphere. It is of interest that the area of heavy rain during this period expanded southward to Springfield, Ill., and southeastward in Indiana as the low level jet axis migrated southeastward. Note the proximity of the jet to the squall line in figure 5. Although there was considerable warm advection over eastern Kansas and Missouri at this time, the air flowing into that area was relatively dry.

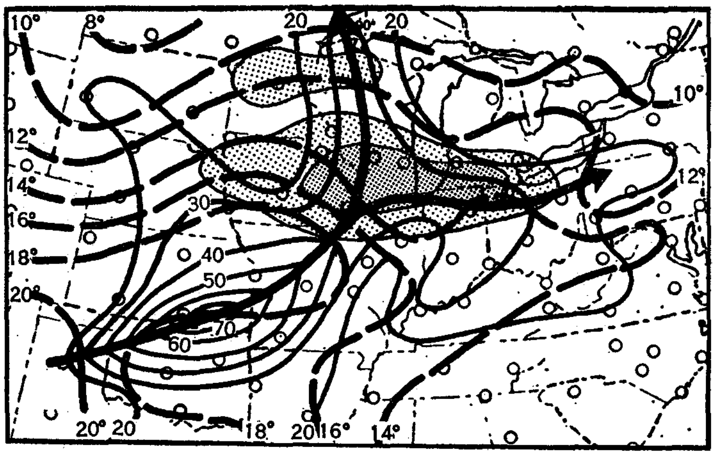

FIGURE 18.—850-mb. chart at 1500 GMT on October 10, 1954. Strongest warm advection has shifted to northwestern Illinois. Heavy precipitation area has expanded westward.

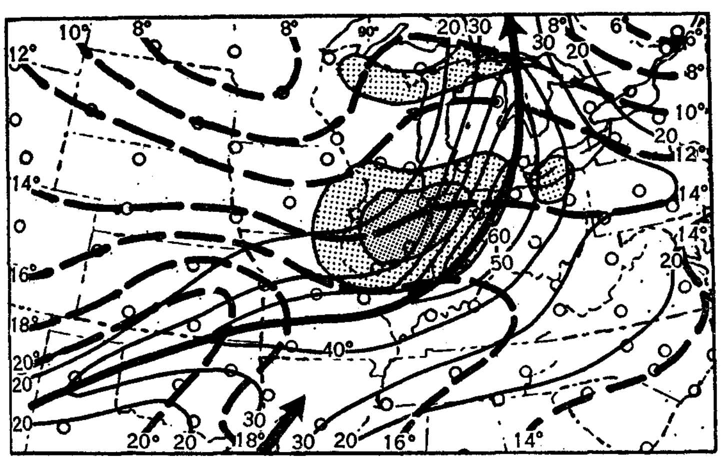

FIGURE 19.—850-mb. chart at 0300 GMT on October 11, 1954. Jet maximum has moved northeastward and jet axis has migrated southeastward.

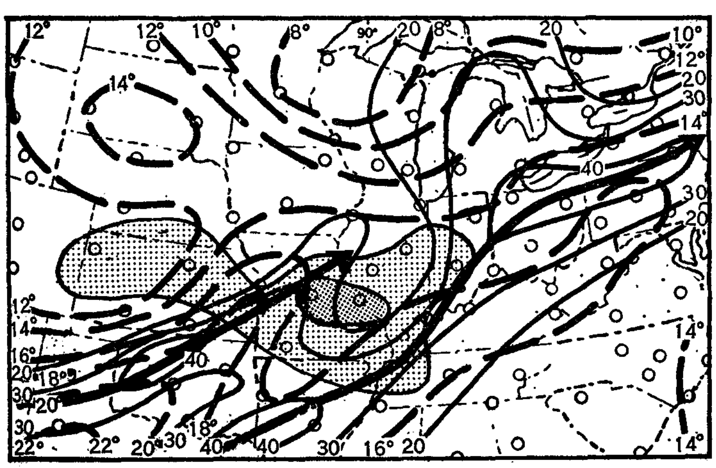

FIGURE 20.—850-mb. chart at 1500 GMT on October 11, 1954. Southern portion of old jet has fractured and a new jet maximum has intensified and moved slowly into Arkansas.

The jet maximum which was over Indiana and western Ohio at 0300 GMT on the 11th (fig. 19) moved eastward and continued to weaken. A new jet maximum which first appeared in northeastern Texas at 1500 GMT on the 10th moved slowly northeastward into Arkansas and intensified slowly. This new jet joined the northern portion of the old jet, and that portion of the old jet through the Southern Plains States had dissipated by 0300 GMT on the 12th. At 1500 GMT on the 11th (fig. 20), there was neither strong warm advection nor strong cyclonic shear in the Chicago area. Consequently there was no appreciable quantity of rain at Chicago during this period. In Missouri, comparatively strong warm advection was present. Air flowing into that area was somewhat more moist than 12 hours earlier and rainfall increased sharply during this period.

On the afternoon of October 11, about 4½ hours after the chart time in figure 20, a brief period of heavy showers resulted in as much as 2 inches of rain in 2 hours on Chicago's South Side. The Chicago Weather Bureau Office accumulated 0.48 inch. The reasons for rain of this intensity during that period cannot be explained by the 850-mb. data either for 1500 GMT on the 11th or for 0300 GMT on the 12th. In addition, there were insufficient upper air data for 2100 GMT on the 11th to explain this occurrence. However, one factor of possible significance is the 4° C. increase in temperature at 850 mb. at Columbia, Mo., between 1500 and 2100 GMT on the 11th while the temperature at Rantoul remained unchanged. This suggests that the temperature gradient and consequently the advective rate had increased in the Chicago area. Available wind data for 2100 GMT indicate that the low-level jet lay through southern Illinois and central Indiana but no strong cyclonic shear was indicated in the Chicago area. Surface analyses show that the front remained northwest of Chicago during this period.

THE JET STREAM AND VORTICITY IN THE HIGH TROPOSPHERE

Most studies of the high-level jet stream in its relation to precipitation have been made at the 300-mb. level.

This level has been so frequently used because, of those mandatory levels reported in radiosonde observations, it normally is the one on which the jet stream is best defined. However, during the period under discussion, the tropopause was above the 200-mb. level and the core of the jet stream was closer to the 200-mb. level than to the 300-mb. level. Since the jet stream was better defined at 200 mb., this level was chosen for our study.

Starrett [7], in his examination of 57 synoptic situations showed that maxima of precipitation usually occur under the jet stream at 300 mb. with a standard deviation of maxima of approximately 5° of latitude. Since even in the locations most favorable for precipitation, 19 percent of Starrett's cases reported no precipitation, one of his conclusions was that the dynamics of the jet stream produce only a broadscale effect on the dynamical fields of convergence and divergence associated with the short baroclinic waves within the westerlies. The good correlation between the high tropospheric jet stream and precipitation found by Starrett was indicative of a tendency for upward motions to be accentuated underneath the jet stream. A more recent investigation by Endlich [8] has shown that strong isanabatic [2] centers lie in or near the jet stream indicating that it is an important vertical transport mechanism. Norquest [9] noted that nearly all precipitation areas of large size over the United States are connected with the jet stream and that even the majority of smaller patchy areas (up to the size of a State) are related to the high-level flow. Other studies have related vertical motion to the vorticity field of the atmosphere. Petterssen [10] showed that "deep" and "very deep" convection are almost exclusively associated with cyclonic vorticity aloft. His results were based on about 300 soundings. The convection was classified as "shallow," "deep," or "very deep" according as the tops of the convective clouds were below the 800-mb. level, between the 600- and 400-mb. levels, or above the 400-mb. level, respectively. Following articles by Sutcliffe [11], Sawyer [12], and Palmén [13] on the relations between the vorticity field of the atmosphere and large-scale vertical motion, Riehl, Norquest, and Sugg [14] developed an equation relating vertical motion in the lower troposphere to the vertical component of the vorticity field of the upper troposphere which associated upward motion with decreasing relative vorticity downstream and downward motion with increasing relative vorticity downstream along streamlines.

The vertical component of relative vorticity is defined by:

$$\zeta = kV - \frac{\partial V}{\partial n}$$

where k is the streamline curvature positive for cyclonic curvature, V, the wind speed, and n is distance along an axis perpendicular to the streamline and positive to the

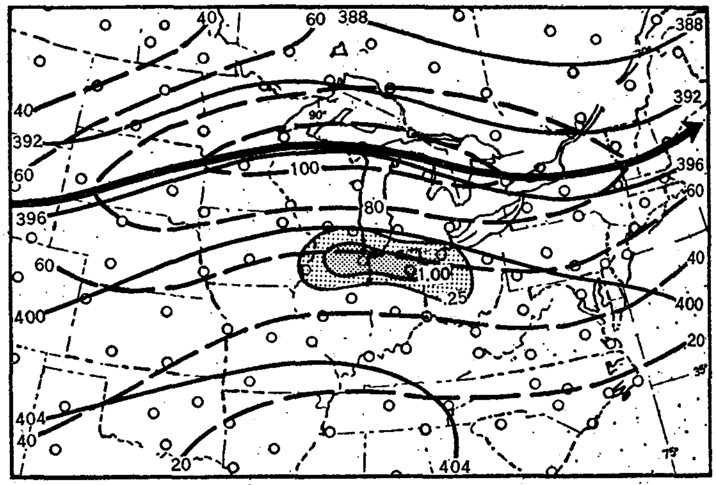

FIGURE 21.—200-mb. chart at 0300 GMT on October 10, 1954. Solid lines are contours in hundreds of geopotential feet. Dashed lines are isotachs labeled in knots. Shading shows 12-hour precipitation for the same interval and period as in figure 17.

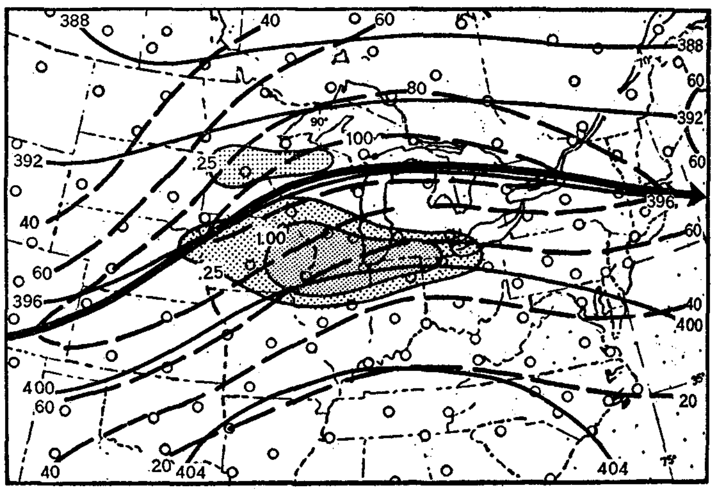

FIGURE 22.—200-mb. chart at 1500 GMT on October 10, 1954. Ridge has moved east of Chicago.

left. According to the hypothesis [14], most potent rain-producing situations should be found when both the curvature and the wind shear are decreasingly cyclonic downstream along the streamlines. Teweles [15] after a test of the hypothesis on 17 days concluded that while a relationship between high level synoptic patterns and the occurrence of precipitation was evident, the relationship was not close enough for forecasting precipitation from high-level information alone. It nevertheless seemed of interest to apply the hypothesis in this case of strong and persistent vertical motion.

In our examination of the vorticity aloft in connection with heavy rains at Chicago, we have treated the 200-mb. contours as streamlines. Since the contours so closely approximate the streamlines, no error of consequence is introduced into our qualitative evaluation.

The 200-mb. chart at 0300 GMT on October 8 showed a jet stream extending northeastward from northern California through western Montana to just north of Lake Winnepeg then southeastward through the southern New England States. During the next 12 hours, the portion

[2] An isanabat is a line of constant vertical velocity.

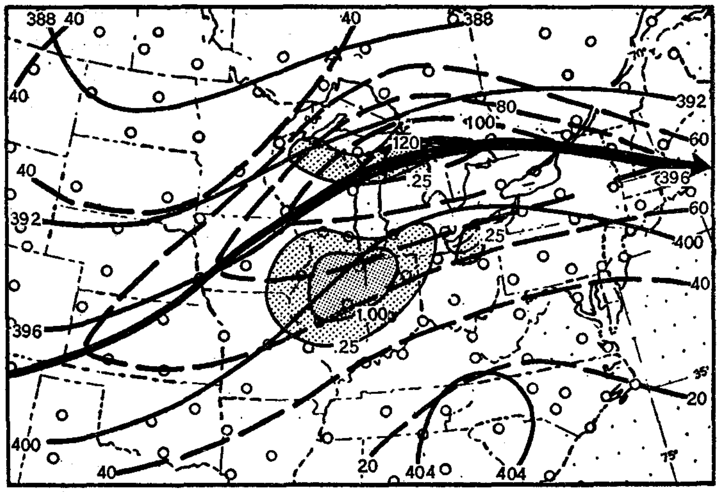

FIGURE 23.—200-mb. chart at 0300 GMT on October 11, 1954.

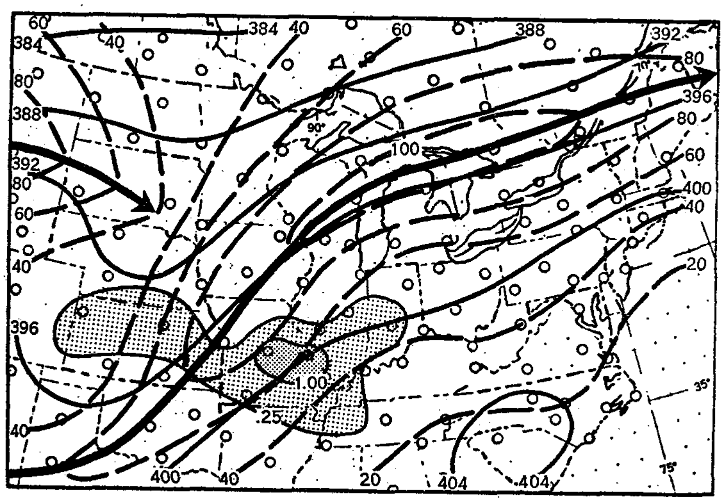

FIGURE 24.—200-mb. chart at 1500 GMT on October 11, 1954.

of the jet stream over central North America was displaced rapidly southward as a Low moved into extreme north-central Canada from the Arctic Ocean. At this time, the jet stream was near the northern border of the United States. During the 9th, the jet stream was displaced southward at a much slower rate and, at 0300 GMT on the 10th, it extended across southern South Dakota and Minnesota through northern Wisconsin and northern Michigan (fig. 21). A jet maximum was located over the Dakotas and Minnesota at 0300 GMT on the 9th. This jet maximum moved very slowly eastward during the next 2½ days. It intensified between 0300 and 1500 GMT on the 9th and then remained strong throughout the period of rainfall with only minor variation in intensity from chart to chart.

During most of the rainy period, the jet maximum was favorably located for precipitation in the Chicago area under the hypothesis [14] being considered. The only exception was the time of initial onset of precipitation. At 0300 GMT on the 10th, about 4 hours after the Chicago Weather Bureau Office first reported heavy rain, the ridge line was a short distance west of Chicago and the maximum wind was on the ridge. Chicago was in a position where at the 200-mb. level there was a slight decrease in both anticyclonic shear and curvature downstream along the streamlines. Both of these conditions contribute to increasing relative vorticity downstream. The same conditions were existent at 300 mb. It appears therefore, that the gradient of relative vorticity in the high troposphere did not initially account for the rain occurrence according to the hypothesis. Further testimony to this was the heavy rain which fell over northern Indiana and over sections of northwestern Ohio where there can be little doubt that the relative vorticity was increasing downstream. Note that during the next 36 hours (figs. 22–24), the 200-mb. ridge moved slowly eastward. On each of the 12-hour charts, heaviest rainfall during the period beginning 8½ hours before and ending 3½ hours after chart time was in an area where at 200 mb. an increase in anticyclonic shear and an increase in anticyclonic curvature downstream were both contributing to decreasing relative vorticity downstream. The vertical motions resulting from the strong divergence aloft inferred from this vorticity field in the high troposphere, in conjunction with favorable conditions in the low levels, contributed to the prolongation of rainfall in the Chicago area. It is reasonable to assume that this condition was also a factor of importance in the intensity of the rainfall.

At 0300 GMT on October 12, 4½ hours after the Chicago Weather Bureau Office's last report of showers on the hourly sequences, the 200-mb. chart indicated that the jet axis had been displaced rapidly southeastward to a position south of the Chicago area. Chicago was no longer in a position relative to the jet maximum to have divergence in the high troposphere since it was in a sector where the relative vorticity was increasing downstream.

SUMMARY

It has been shown that the air flowing into the Chicago area throughout the rain period was warm and very moist. This air had potential instability exceeding that necessary to produce thunderstorms. An increase in average winds between gradient level and 20,000 ft. increased the rate of inflow of moist air into the area. At the initial onset of heavy precipitation, an increase in low level warm advection had developed as a result of strengthening of an 850-mb. jet which extended northeastward from the eastern border of the Texas Panhandle. The 850-mb. warm tongue, which extended east-northeastward from western Kansas, crossed the 850-mb. jet in northern Illinois. This increase in low level warm advection implies increased upslope convergence Frontal convergence apparently was also a part of the initial rain-producing mechanism. The surface chart 7½ hours after heavy rain was first reported by the Chicago Weather Bureau Office showed that the front had moved north of Chicago. Chicago was in the warm air sector during the remainder of the 48-hour period of rains. At 1500 GMT on the 10th, the low level

warm advection was still present, but much stronger over northwestern Illinois than in the Chicago area. Consequently the heaviest rain area shifted to northwestern Illinois. The 850-mb. temperature gradient there had increased due to both warming from the southwest and precipitational cooling over northern and central Illinois and northern Indiana.

In the meantime, the 200-mb. ridge moved slowly eastward and the vorticity field associated with the high tropospheric jet maximum had created a zone of strong divergence aloft over the area of concern. At 0300 GMT on the 11th, warm advection in the Chicago area was weak. However, northeastward movement of the low level jet maximum together with southeastward migration of the jet axis had created strong horizontal convergence in the low levels over northern Indiana and over most of Illinois. In the high troposphere, the divergence inferred from decreasing relative vorticity downstream, was persistently strong. At 1500 GMT on the 11th, there was neither strong warm advection nor strong horizontal convergence over the Chicago area in the low levels. Rainfall decreased sharply during this period. Divergence continued in the high troposphere.

The brief period of heavy showers at Chicago during the afternoon of the 11th is not fully explained. However, sparse data at 850 mb. near the time of occurrence suggest that the advective rate of warm air had increased. Divergence in the high troposphere was still present. The last time the Chicago Weather Bureau Office reported showers on hourly sequence reports was at 2230 GMT on the 11th. Rawinsonde data 4½ hours later indicated that much drier air was flowing into the Chicago area from the Great Plains States except in a shallow layer near the ground. The 200-mb. jet axis had been displaced rapidly southeastward and Chicago was no longer in a position relative to the jet maximum to have divergence in the high troposphere.

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